High Resolution Spectroscopy of X-ray Binaries

Frits Paerels

Columbia University

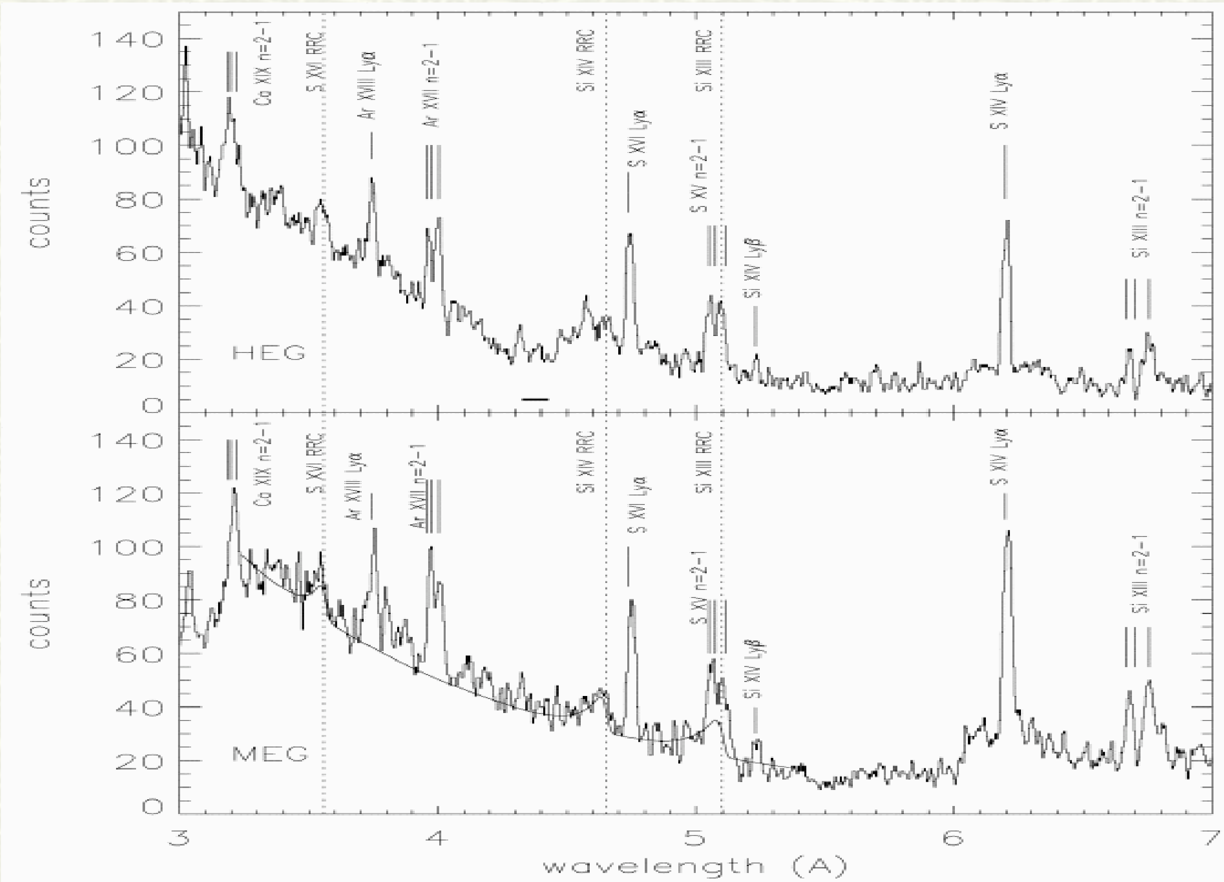
First Constellation X Workshop...,
Columbia, May 5-7, 2003

High Resolution Spectroscopy of X-ray Binaries

- At last count: 41 objects with high resolution (diffraction grating) spectra in *Chandra* and *XMM-Newton* archives (massive binaries, LMXB's, CV's); approximately 50-60 papers
- Huge diversity of spectra; by implication: huge range in physical conditions in accretion flows/environments
- Most work so far exploratory; detailed analysis still to be undertaken in many cases
- Focus on three topics:

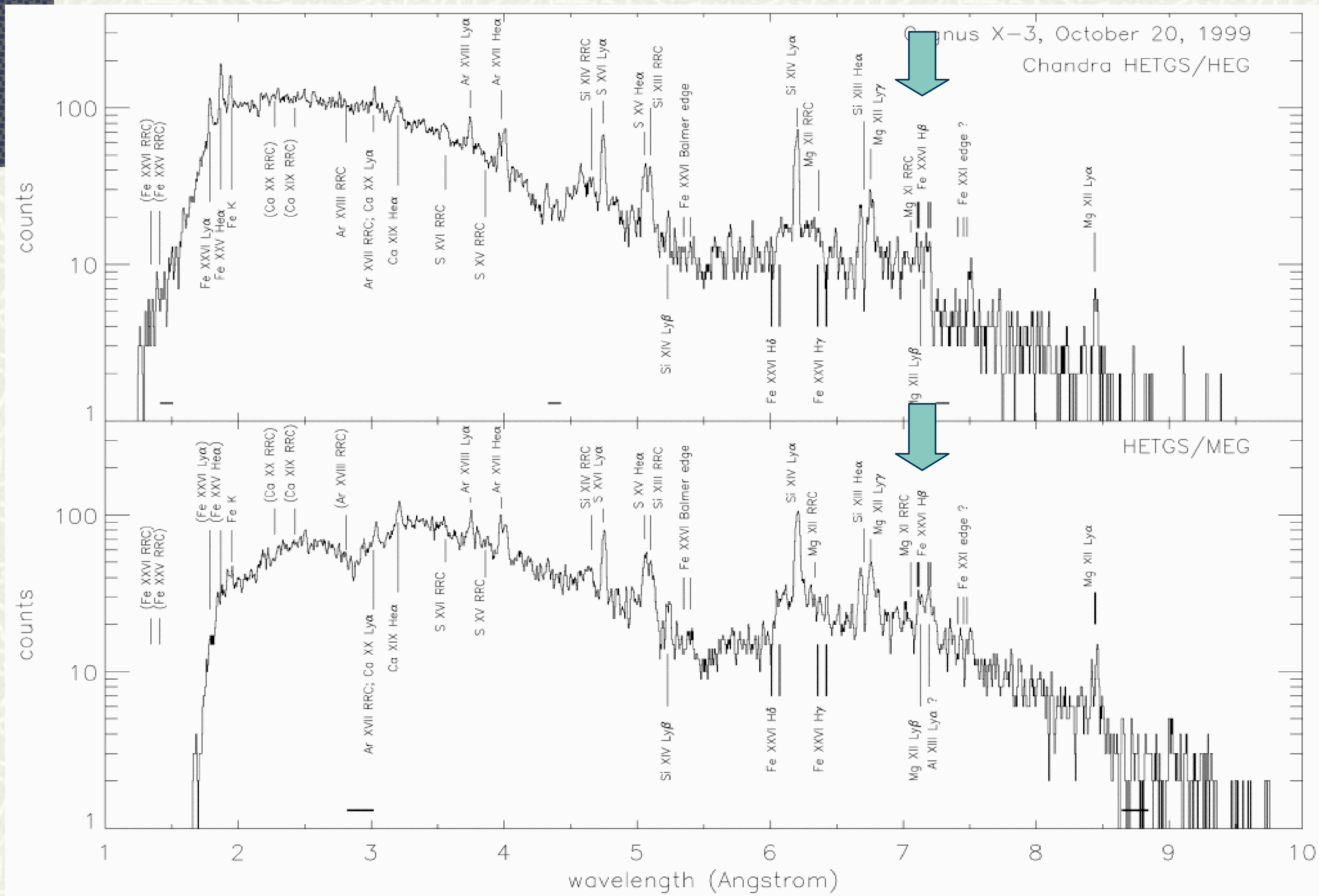
    1. Spectroscopy of Radiation Driven Plasmas
    2. Dynamics and Energetics of Accretion
    3. Binary Evolution, Physics of Compact Objects

1. Spectroscopy of Radiation Driven Plasmas



X-ray Photoionized Wind From Wolf-Rayet star In Cygnus X-3

(Chandra HETGS, Paerels et al., 2000, *Ap.J.*, **533**, L135)



First Constellation X Workshop...,
Columbia, May 5-7, 2003

X-ray Photoionized Gas in Cygnus X-3

Signatures of X-ray Photoionization:

Discrete Spectrum Dominated by Recombination

* Narrow Radiative Recombination Continua

  Gas is COOL: $kT_e << \chi$

  in fact: $\Delta E(RRC) \cong kT_e$

  (powerful temperature diagnostic)

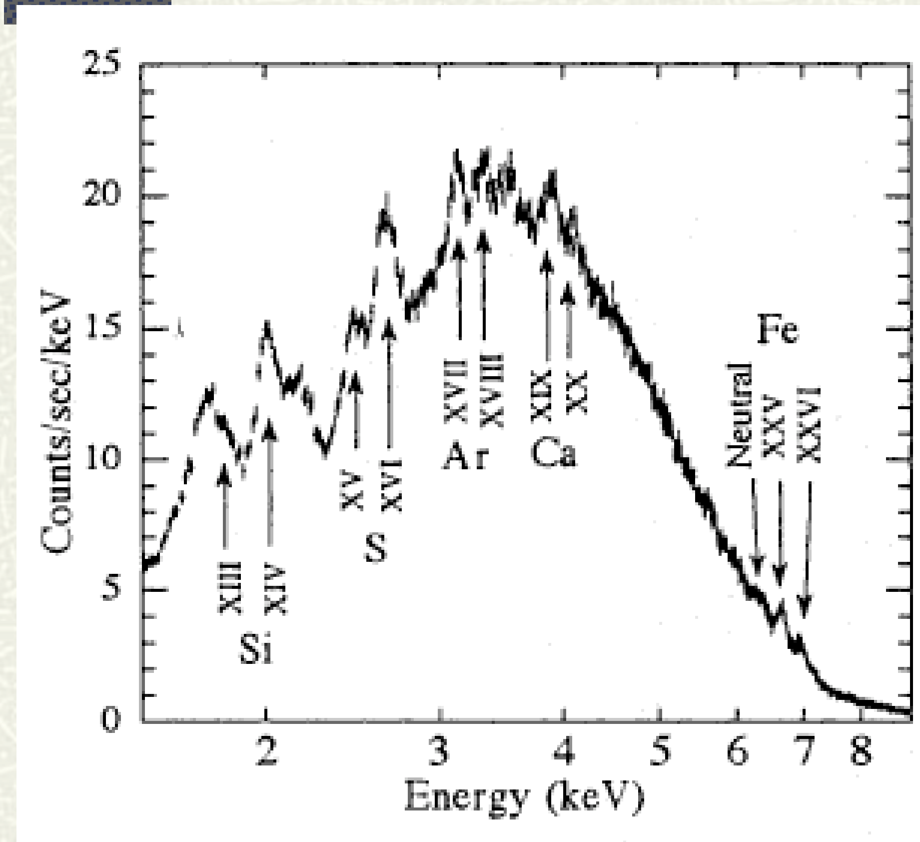
* He-like Triplets: F, I brighter than R
* Appearance of Fe XXVI Balmer Series!

(* Fe L weak compared to low/mid-Z K shell spectra)

All Lines Are Resolved: Doppler Broadening

Other Massive Binaries: Similar Characteristics

GRB Afterglow Spectroscopy: a Warning

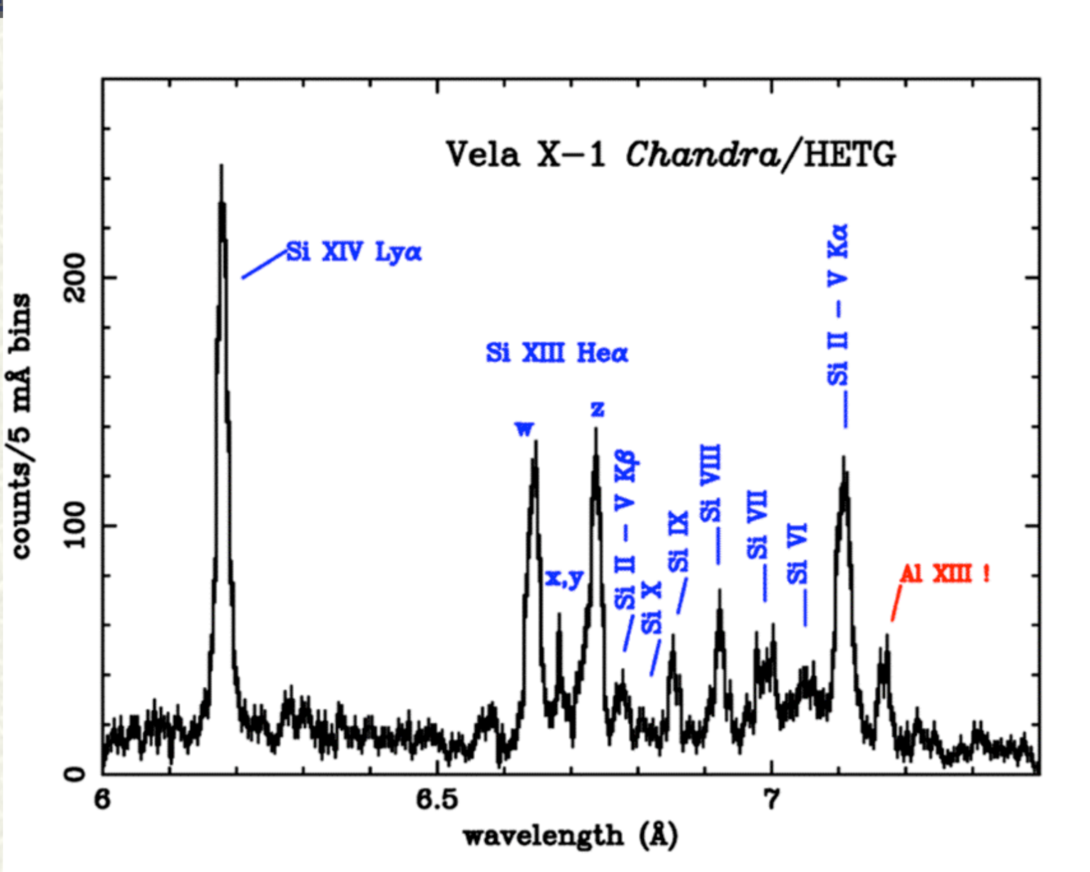


Recombination spectrum at CCD resolution:

Only ONE unblended unique diagnostic: S XVI RRC (3.494 keV)!

Cyg X-3/ASCA; Kitamoto et al. 1994, PASJ

Fluorescent Emission



Courtesy Masao Sako

Fluorescence uniquitous in XRB

Full Si K spectrum in Vela X-1 !

Note presence of Si II-V: contains Si IV (UV resonance lines): additional constraint on optical depth through wind

Interesting radiative transfer: resonant Auger destruction (Liedahl 2003)

Potential

* Ionization structure of the wind, combined with velocity resolution:
  Can unfold dynamical and density structure

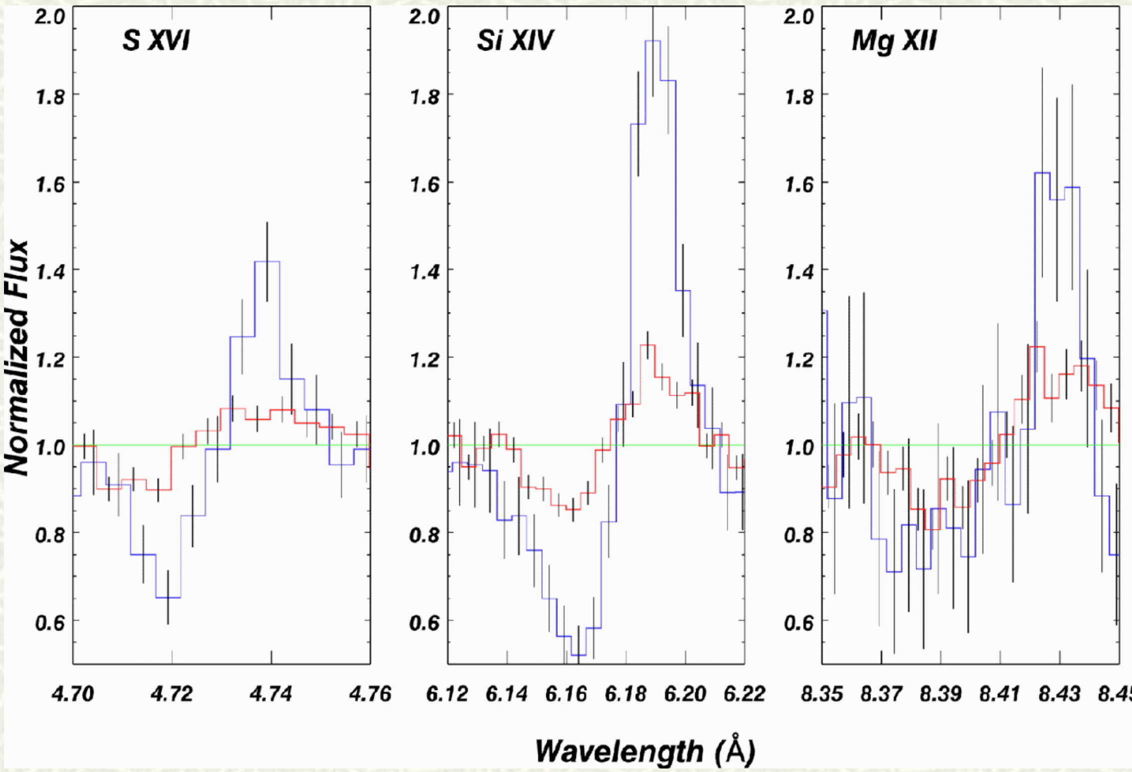
* Combined with optical depths from absorption/radiative transfer:
  problem overconstrained (consistency check; additional parameter such as clumpiness (see next topic))

Resonance scattering: Cen X-3 (Patrick Wojdowski)

Cold Compton scattering: GX 301-2 (Shin Watanabe)

2. Dynamics and Energetics of Accretion Flows

P Cygni Profiles in Strong Resonance Lines in Cir X-1



Similar features in several Other binaries (Cyg X-3, Cyg X-1, …)

Absorption and emission By photoionized wind Flowing off the accretion disk

Chandra HETGS/ Schulz & Brandt, 2002, Ap. J.

Absorption/Emission from Outflows

Measure emission line intensities, absorption optical depths:

Constrain $EM = n_e^2 V, \tau = nl$

(NB: $EM = \int n_{i+1} n_e dV, \tau = \int n_i dl$

so need model for the ionization structure)

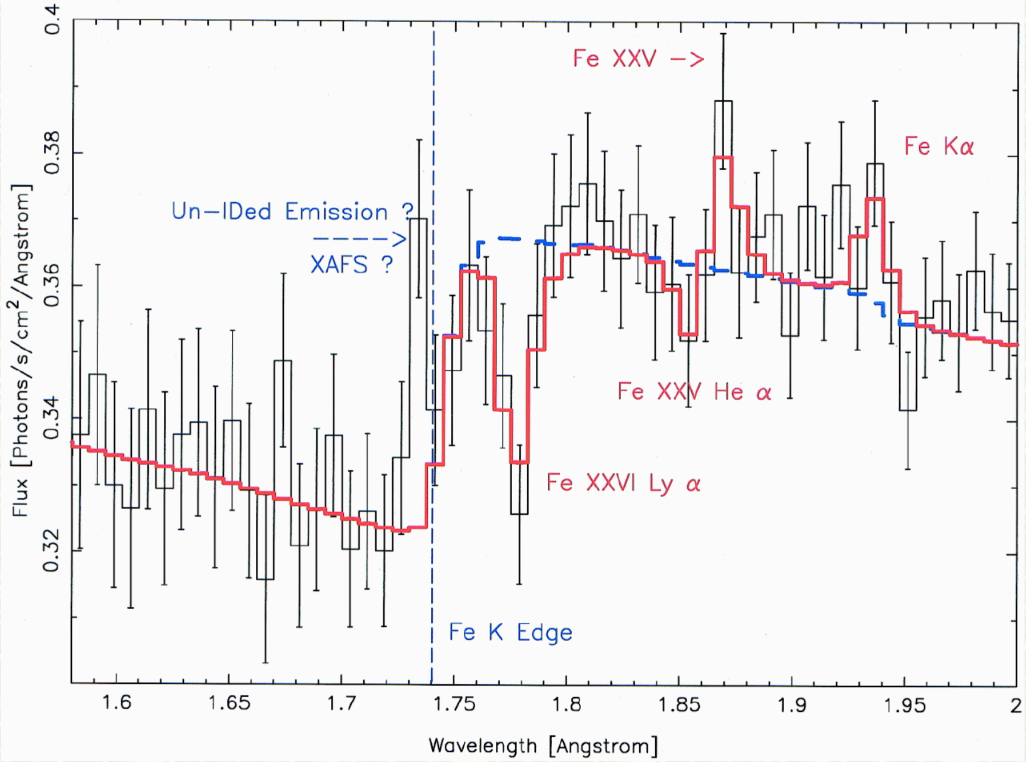
Measure velocity field; assume geometry, assume abundances:

Constrain density and velocity structure of outflow:

Estimate mass/momentum outflow rate, kinetic luminosity

Completely analogous to studies of mass loss from O stars from UV resonance line absorption spectroscopy

Mass Accretion and Outflow in GRS1915+105



Chandra HETGS/ Lee et al. 2002, Ap. J.

Outflow in GRS1915+105

Estimate mass outflow rate: need density, velocity at some fiducial radius

Absorption in Fe XXVI, XXV resonance lines: ionization parameter, column density

Known L (hence nr^2); assume thin shell geometry, limit on outflow velocity

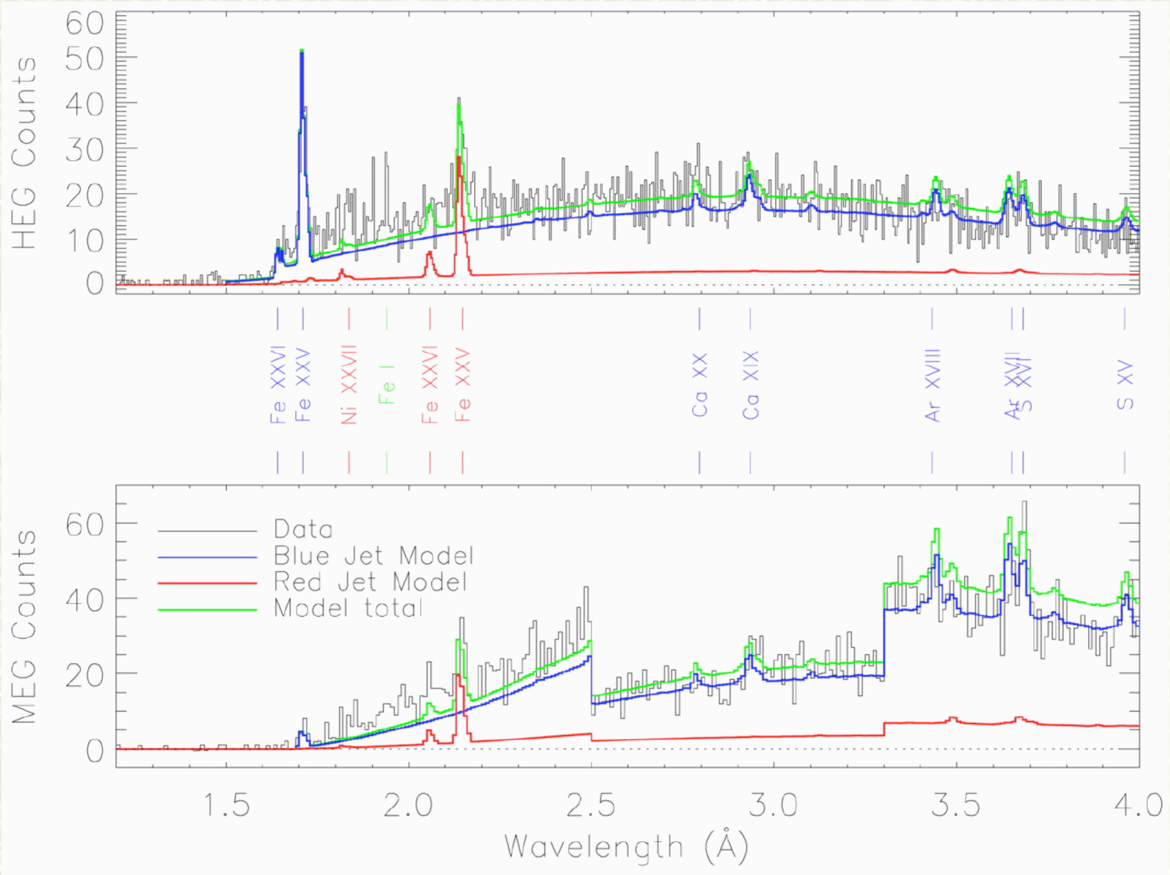
Estimate mass outflow rate:

$$\dot{M} = 9.5 \times 10^{18} (\Omega / 4\pi)\, g\, s^{-1}$$

Accretion rate (from L):

$$\dot{M} = 7 \times 10^{18}\, g\, s^{-1}$$

Jet Energetics: SS433



Chandra HETGS/ Marshall et al. 2002, Ap. J.

Jet Energetics: SS433

Spectroscopy:

Gas is in Collisional Equilibrium

Velocity spread along line of sight: jet expansion

Direct density measurement from He like triplets

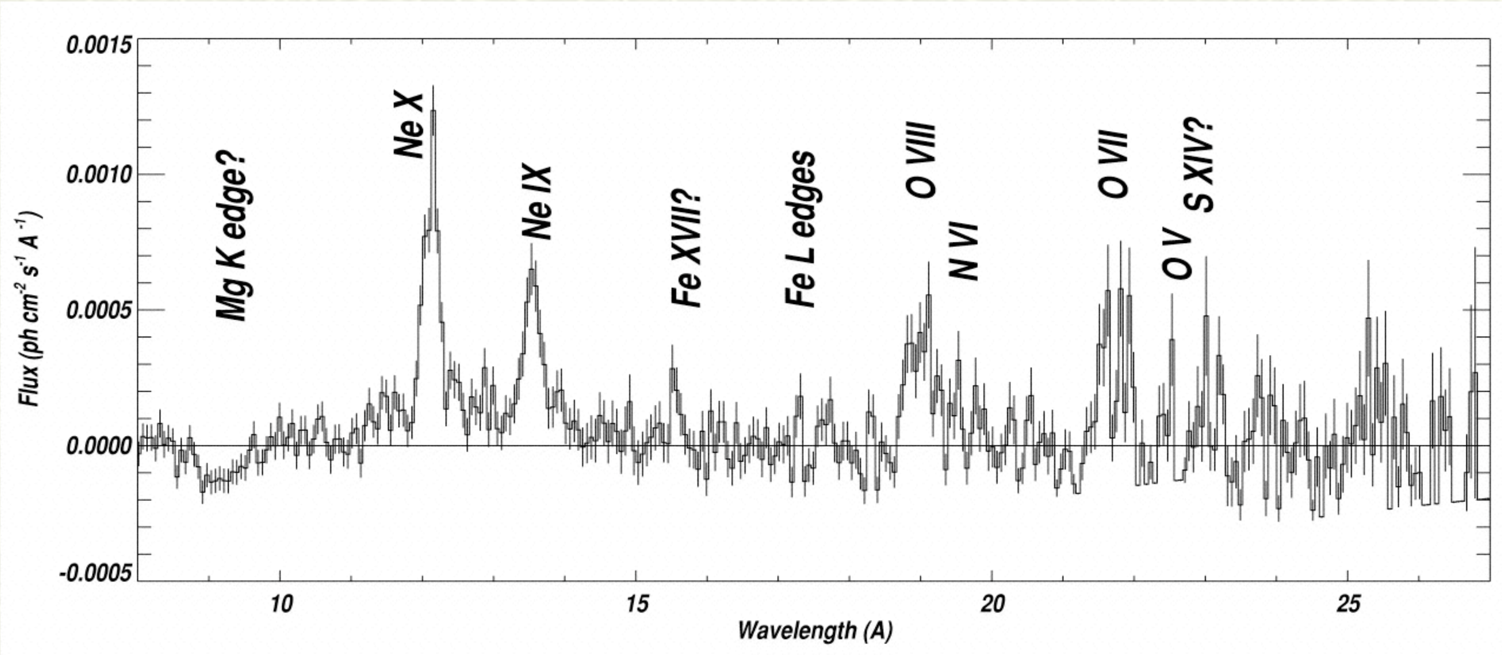
Asssume jet geometry

$$\dot{M} = 1.5 \times 10^{-7} M_{solar} yr^{-1}$$

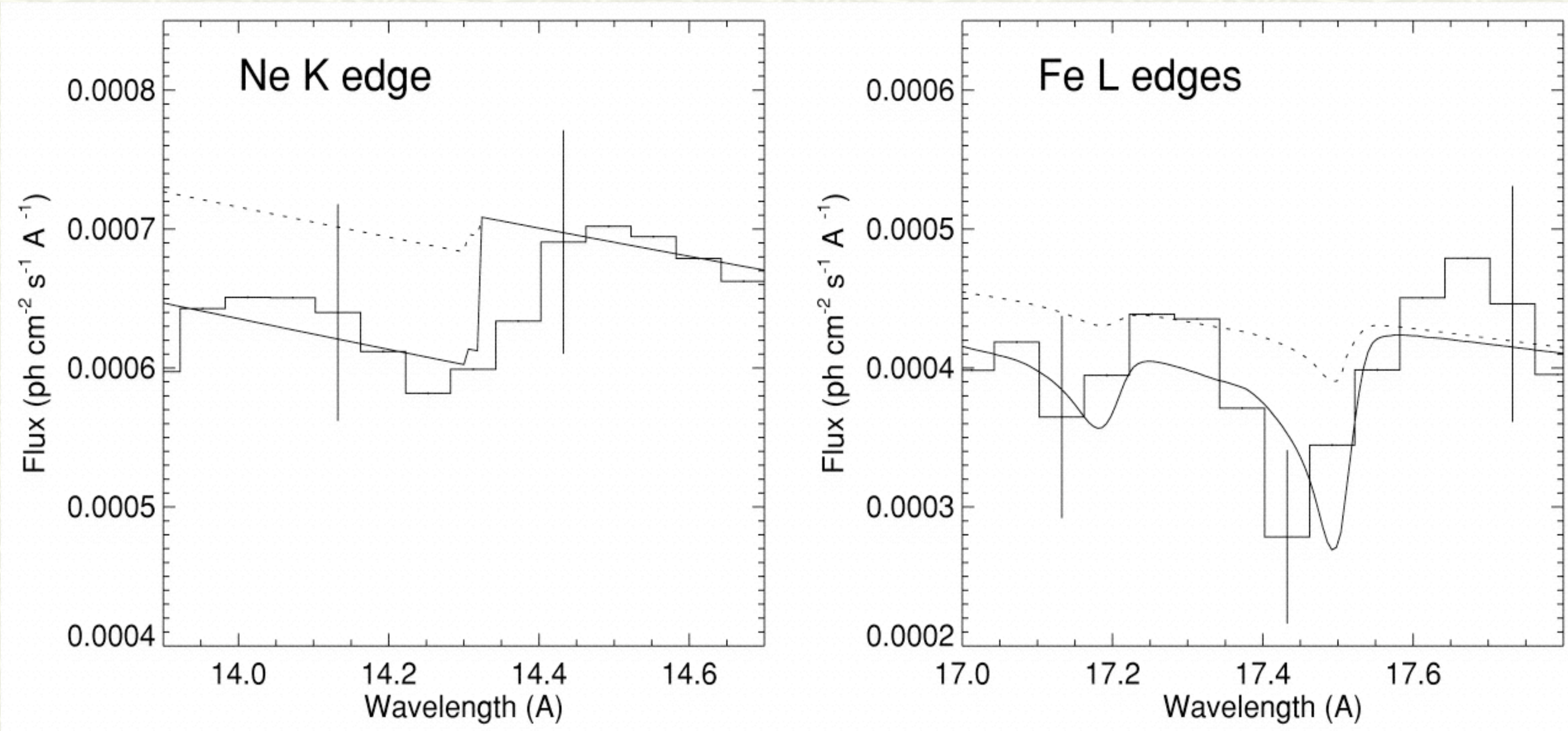
And with known jet velocity:

$$L_{kinetic} = 3.2 \times 10^{38} erg\, s^{-1} \sim 1000\, L_{\gamma}$$

Binary Evolution; Physics of Compact Objects



Abundance Anomalies: 4U1626-67



Abundance Anomalies

Mass Donor is a 0.02 M_{solar} White Dwarf

Measured Ne/O = 0.22

Consistent with core composition of C-O WD after Crystallization and fractionation!

(could also be O-Ne-Mg WD if detection of Mg K edge confirmed)

Crystallization/Fractionation: important issues in WD Cooling and calibration of age of the Disk, GC's

Concluding

Spectroscopy works: we are measuring densities, temperatures, velocities, abundances, and inferring important quantities (accretion energy budget, stellar structure and evolution)

XRBs are bright, can serve as templates for spectroscopy of radiation driven plasmas in AGN (radiative transfer effects)

Most important line complexes resolved; velocity fields resolved at current resolving power: spectroscopy with Chandra, XMM, and Astro-E2 definitive?

Physics of compact objects: spectroscopy of X-ray bursts

30 X-ray Bursts from EXO0748-676 with XMM-RGS